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A comparison of the Potential Transpiration calculation for a 24 hour period with that for day and night separately

by M C Wylie

Introduction

At present the Met.Office Rainfall and Evaporation Calculation System (MORECS), when calculating transpiration, uses values of temperature, windspeed, vapour pressure, and the nett radiation incident on the Earths surface which do not take into account differences between day-time and night-time.

In practice, however, both the meteorological conditions and the physiology of the plant will vary between day and night-time. During the day there is short-wave radiation falling on the earth, and a heat flux into the ground, with unstable or neutral conditions; whilst at night the heat flux is out of the ground and conditions are neutral or stable. During the night the plant stomata will close, thus producing a large stomatal resistance.

By taking day and night values separately, a more accurate indication of potential transpiration should be obtained, and the purpose of this paper is to investigate whether, by doing this, a significant difference in the calculated potential transpiration will occur.

The Penman equation

The equation used to calculate evapotranspiration is:

$$PT = \frac{\Delta\,(RNS-RNL-G) + 43\,(SVP-VP)/r_a}{\Delta + 0.66\,(1 + r_s / r_a)}$$

where: PT = Potential Transpiration in mm/day.

Δ = Slope of S.V.P curve in mb/°C (See Appendix)

RNS = Shortwave radiation (See Appendix) mm/day

= R_a (1 - reflection coefficient)$(a+b.n/N)$

R_a = Shortwave radiation incident on the top of the atmosphere in mm/day. (See Appendix)

a,b = Cowley coefficients, a = 0.23, for b see Appendix.

n = Sunshine duration in hours (See Appendix)

N = Daylength in hours (See Appendix)

RNL = Nett longwave radiation

= $1.88 \times 10^{-9} B(T + 273)^4 (0.56 - 0.08\sqrt{VP})(0.1 + 0.9\,n/N)$ in mm/day

B = Longwave correction term (See Appendix)

T = Air temperature in degrees Celsius

VP = Vapour pressure in mb.

SVP = Saturation vapour pressure in mb (See Appendix)

G = Ground heat flux in mm/day

r_s = Stomatal resistance in s/m

r_a = Aerodynamic resistance in s/m

0.66 = Psychrometric constant in mbar/°C

~~17.2~~ 43m = is an empirical constant derived by Penman, which includes the roughness ~~constant m, where~~

$$m = \left[\frac{\log_e (z/z_{op})}{\log_e (z/z_o)}\right]^2$$

Z = reference height = 1.2m

Z_{op} = 1.37 mm (see Thom and Oliver 1977)

Z_o = roughness length which is of the order of 1/10 of the crop height and was given by 0.002m for short grass and by 0.02m for longer grass.

Extraction of Data

The hourly mean values of temperature, windspeed and vapour pressure for Elmdon (Birmingham airport) were extracted for each month, averaged over the period from 1 Jan 1970 to 31 Dec 1979. The monthly mean values of each parameter were calculated for the day, the night, and for the full twenty-four hour period. The daylength in hours, number of hours of sunshine, Cowley 'b' coefficient, R_a , B, and the daytime stomatal resistance were also obtained for each month, for this station. (See Appendix and Figures 1 and 2). The parameters averaged over the 24 hour period more closely approached the daytime values in summer and the night-time values during the winter.

Calculation

Considering each term in the equation separately for day and for night:

Δ - This is given by the expression

$$\Delta = \frac{4098.026}{(T+237.3)^2} \times \text{EXP}\left(19.0786 - \frac{4098.026}{T+237.3}\right)$$

and so day and night values can be calculated from the appropriate value of T.

RNS - There is negligible shortwave radiation falling on the earth at night, so this value was set at zero. During the day it was calculated using the daytime values of R_a, b, n, N. The reflection coefficient was put equal to 0.25 for grass.

RNL - This is equal to the difference between the incoming and outgoing longwave radiation and is calculated for day and night separately, using the appropriate values of B, T, VP, n and N.

G - This is the heat flux to the ground and can be considered as being a fixed proportion of the total incoming radiation. During the day it was given by 0.2(RNS-RNL) and during the night by -0.57 RNL, a value which gave approximately zero total heat storage when averaged over the whole year. (Monteith 1956). (See Figure 3)

S.V.P can be calculated separately for day and night using the formula

$$SVP = \text{EXP}(19.0786 - 4098.026/(T + 237.3))$$

The vapour pressure deficit (SVP-VP) is shown in Fig. 2.

r_a - The aerodynamic resistance can be considered as being a function of the windspeed. During the day Penmans formula for r_a was used. (Thom and Oliver, 1977):

$$r_a = \frac{250}{m(1 + 0.54u)}$$ Where u is the windspeed at 1.2m in m/s.

At night, neutral stability was assumed and Penmans' neutral stability formula

$$r_a = \frac{315}{mu}$$ was used.

As the windspeed was measured at 10m it was reduced to 1.2m for both day and night using the neutral stability approach, ie.

$$\frac{U(z_2)}{U(z_1)} = \frac{\log_e(z_2/z_o)}{\log_e(z_1/z_o)}$$ Where $U(z)$ = windspeed at height z.

The variation of m and r_a as z_o is varied are shown in figure 5.

r_s - During the day monthly values were used (see Appendix). At night a constant high value of 500 s/m was used as the stomata will be closed at night.

Results

A calculation was made of potential transpiration for day and for night for Elmdon and the sum of these was compared to the 24 hourly value which would be produced by MORECS in its present form. The results are shown in figures 4a and 4b.

(NB. In these figures the values for day and for night are in mm/daytime period and mm/night-time period).

Conclusions

It can be seen from figures 4a and 4b that the extent to which the 24 hour average figure differs from that calculated with day and night separately depends on the value of z_o used. For large values of z_o (tall grass) the 24 hour value is larger, while for smaller values of z_o (short grass) the values are very similar. During the months March to October the maximum difference is about 0.2 mm/day (about 5%). Although during the winter larger percentage differences occur, these are not so important as the rainfall is then much greater than the potential transpiration.

This indicates that with the equation used by MORECS at present a 24 hour calculation of potential transpiration is satisfactory and that separate calculations for day and night are not worthwhile.

Any comments or suggestions on this paper should be referred to the author.

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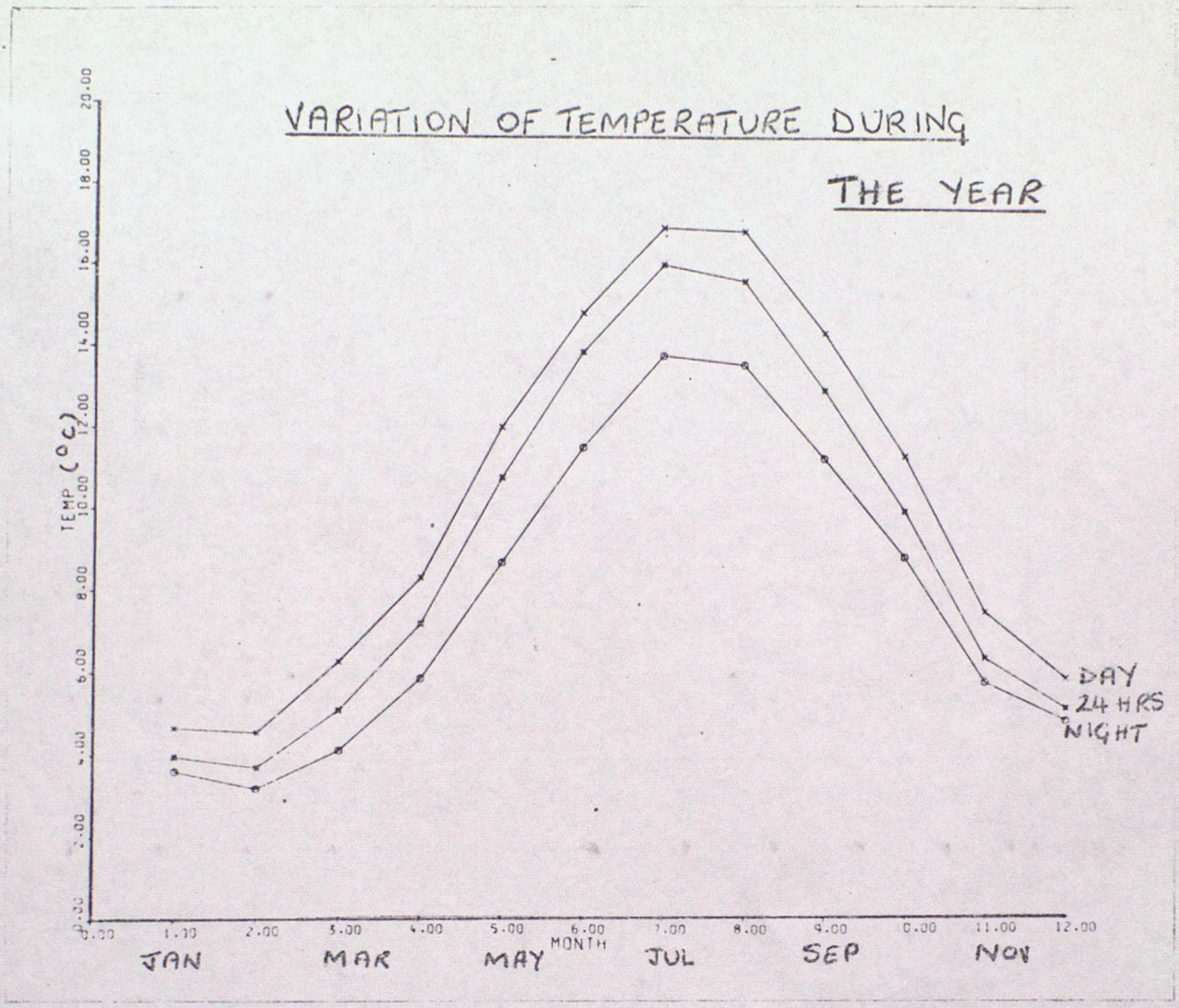
References

A S Thom and H R Oliver 'On Penmans equation for estimating regional evaporation' 1976. Quart J.R. Met. Soc. (1977), 103 pp 345-357.

J L Monteith 'The heat balance of soil beneath crops' 1956. Arid Zone Res. XI. Climatology and Microclimatology, Proc. Canberra Synop. Oct 1956 (UNESCO).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Longwave Correction Term, B	1.04	1.06	1.09	1.12	1.16	1.17	1.18	1.17	1.16	1.12	1.08	1.05
Hours of Sunshine, n	1.4	2.1	3.4	4.2	6.1	6.4	6.2	5.5	4.5	3.1	2.6	1.6
Daylength Hours, N	8.0	9.7	11.6	13.8	15.7	16.8	16.4	14.8	12.6	10.5	8.6	7.6
Ra (mm/day)	3.0	5.3	8.6	12.5	15.6	17.2	16.6	14.0	10.3	6.6	3.7	2.5
Cowley b Coefficient	0.42	0.49	0.52	0.53	0.55	0.52	0.50	0.49	0.48	0.47	0.47	0.45
Daytime Stomatal Resistance	50	50	40	30	30	30	30	30	30	40	50	50
Day Δ mb/degree C	0.60	0.59	0.66	0.74	0.92	1.08	1.22	1.21	1.05	0.89	0.71	0.64
Δ Night	0.56	0.54	0.58	0.64	0.76	0.90	1.02	1.01	0.88	0.76	0.64	0.60
Δ 24 hours	0.57	0.56	0.61	0.69	0.86	0.99	1.16	1.13	0.97	0.82	0.66	0.61
SVP Day (mb)	8.51	8.43	9.50	10.93	14.0	16.81	19.23	19.13	16.28	13.34	10.31	9.23
SVP (mb) Night	7.90	7.66	8.17	9.23	11.21	13.54	15.69	15.46	13.29	11.29	9.16	8.59
SVP(mb) 24 hours	8.10	7.94	8.76	10.12	12.89	15.07	18.14	17.67	14.84	12.19	9.54	8.77
Short-wave (Day) Radiation	0.68	1.34	2.47	3.67	5.19	5.52	5.22	4.33	3.10	1.83	1.03	0.61

FIGURE 1.


VARIATION OF TEMPERATURE DURING THE YEAR
TEMP (°C)
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
JAN
MAR
MAY
JUL
SEP
NOV
MONTH
DAY
24 HRS
NIGHT

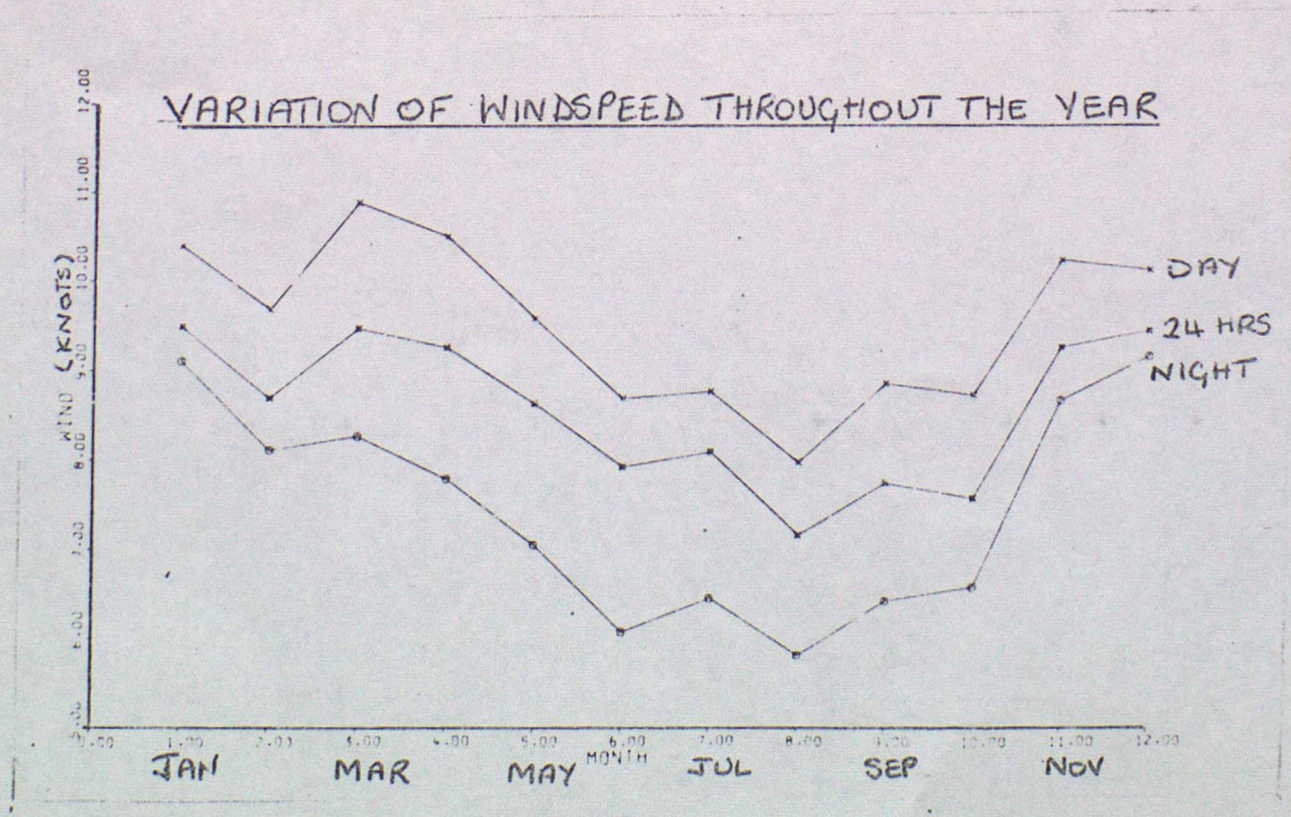
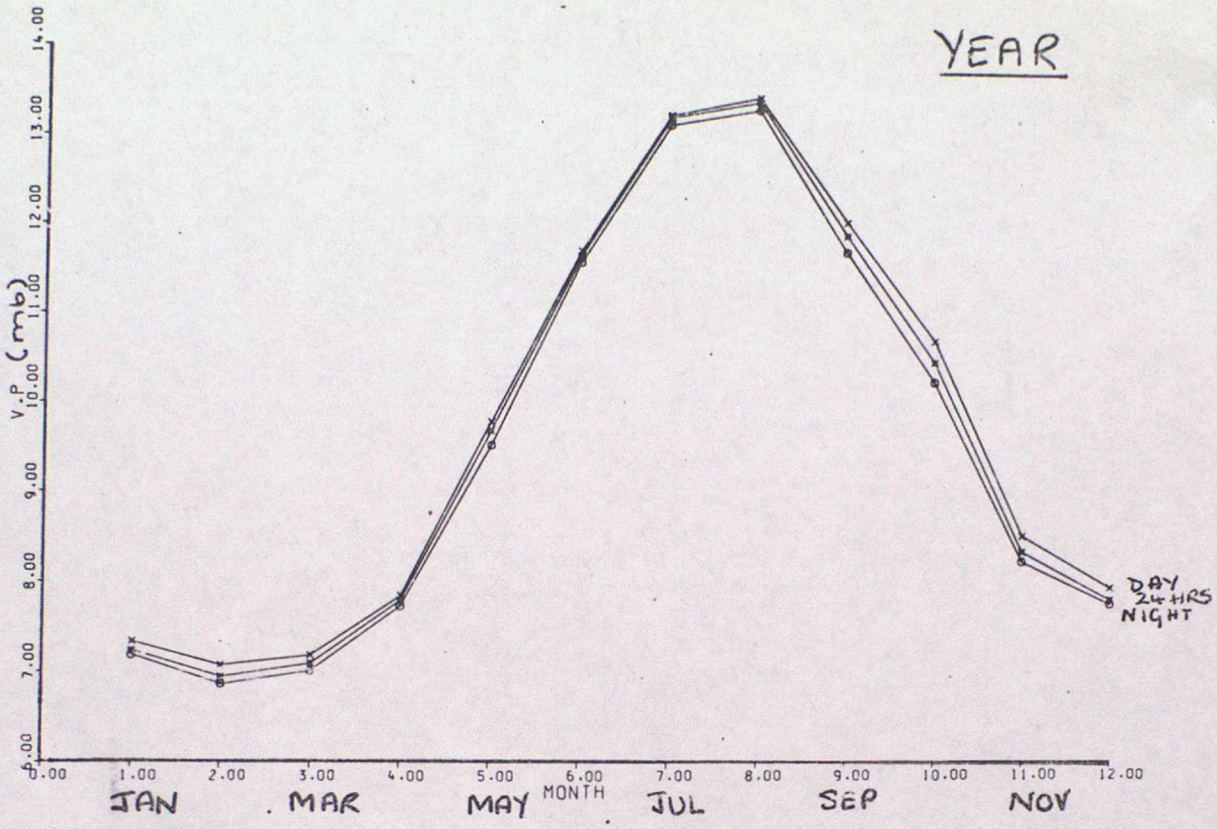
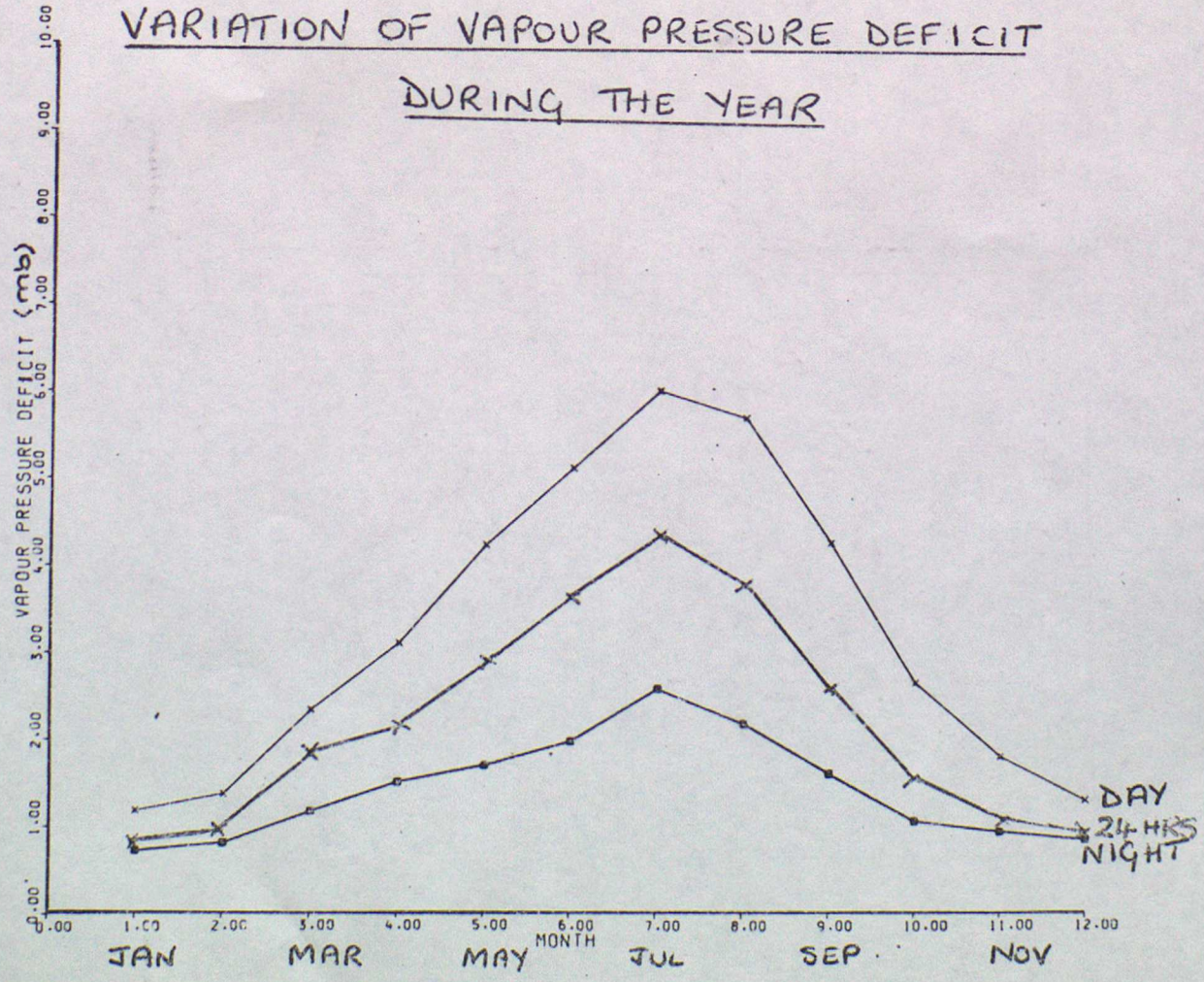

VARIATION OF WINDSPEED THROUGHOUT THE YEAR
WIND (KNOTS)
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
11.00
12.00
JAN
MAR
MAY
JUL
SEP
NOV
MONTH
DAY
24 HRS
NIGHT

FIGURE 2

VARIATION OF VAPOUR PRESSURE DURING THE YEAR



VARIATION OF VAPOUR PRESSURE DEFICIT DURING THE YEAR



: FIGURE 3

VARIATION OF HEAT FLUX TO GROUND DURING THE YEAR

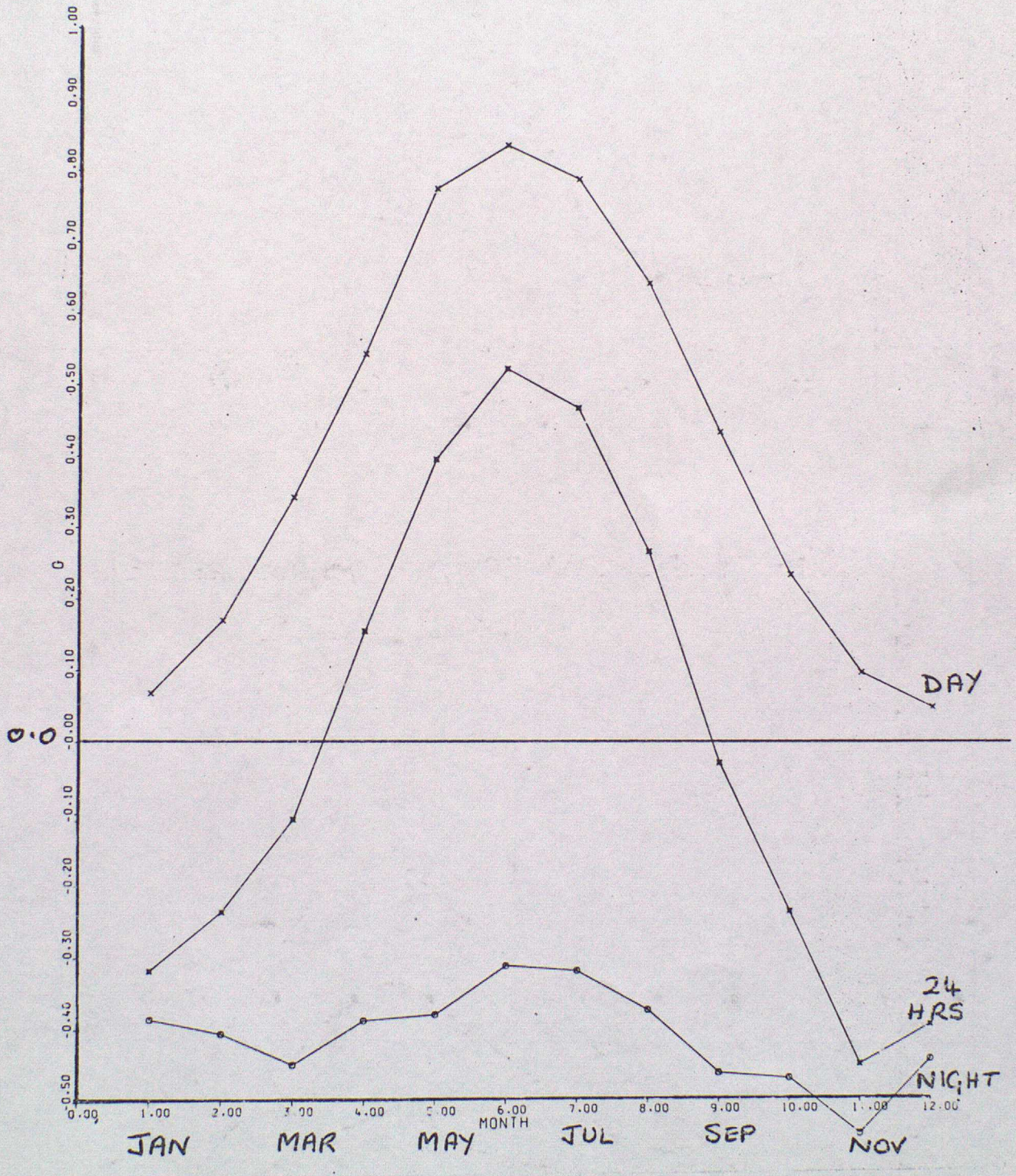


FIGURE 4a

VARIATION OF POTENTIAL TRANSPIRATION

DURING THE YEAR

(Z_o = 0.02 m)

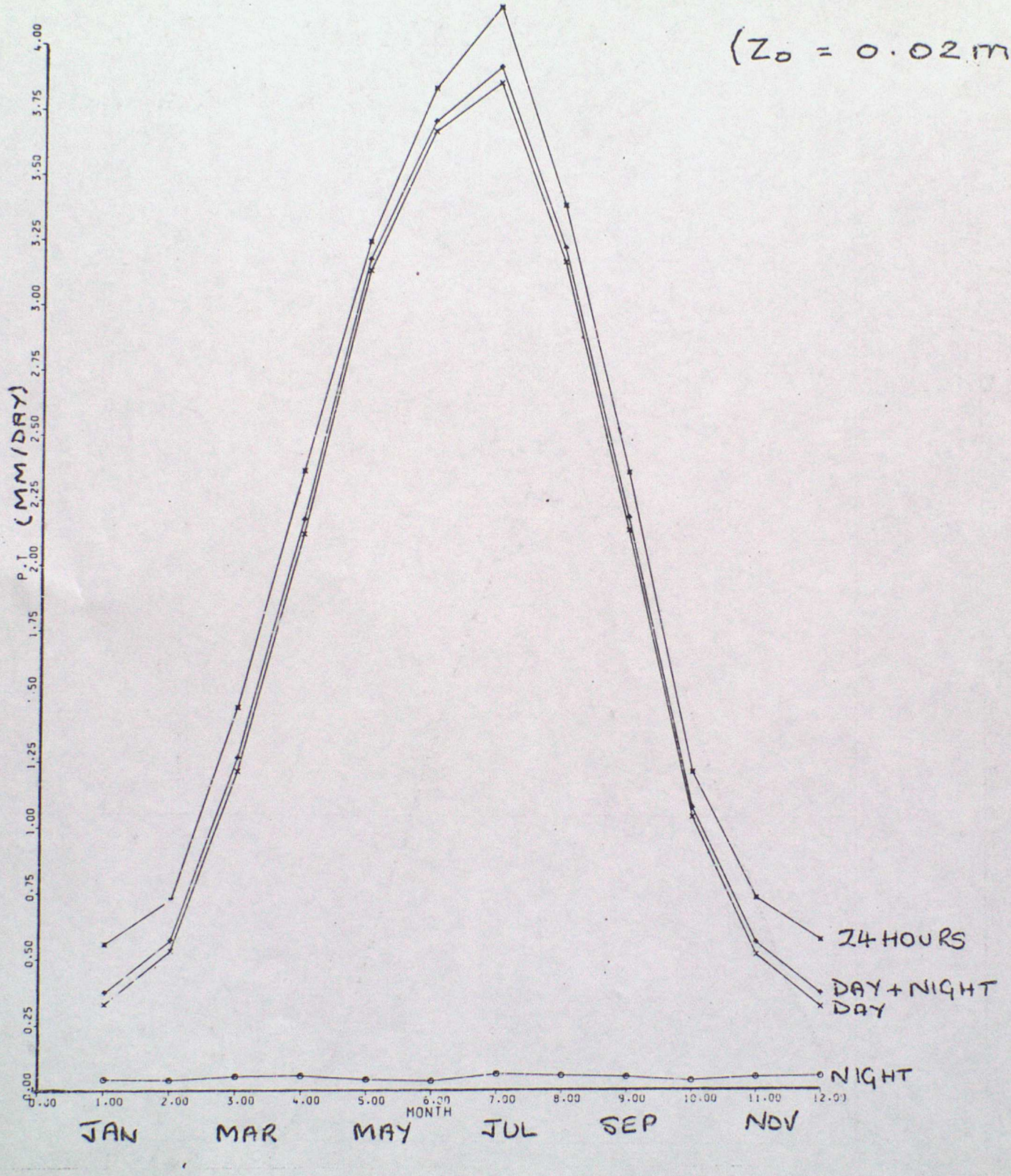


FIGURE 4b

VARIATION OF POTENTIAL TRANSPIRATION DURING THE YEAR

($Z_o = 0.002$ m)

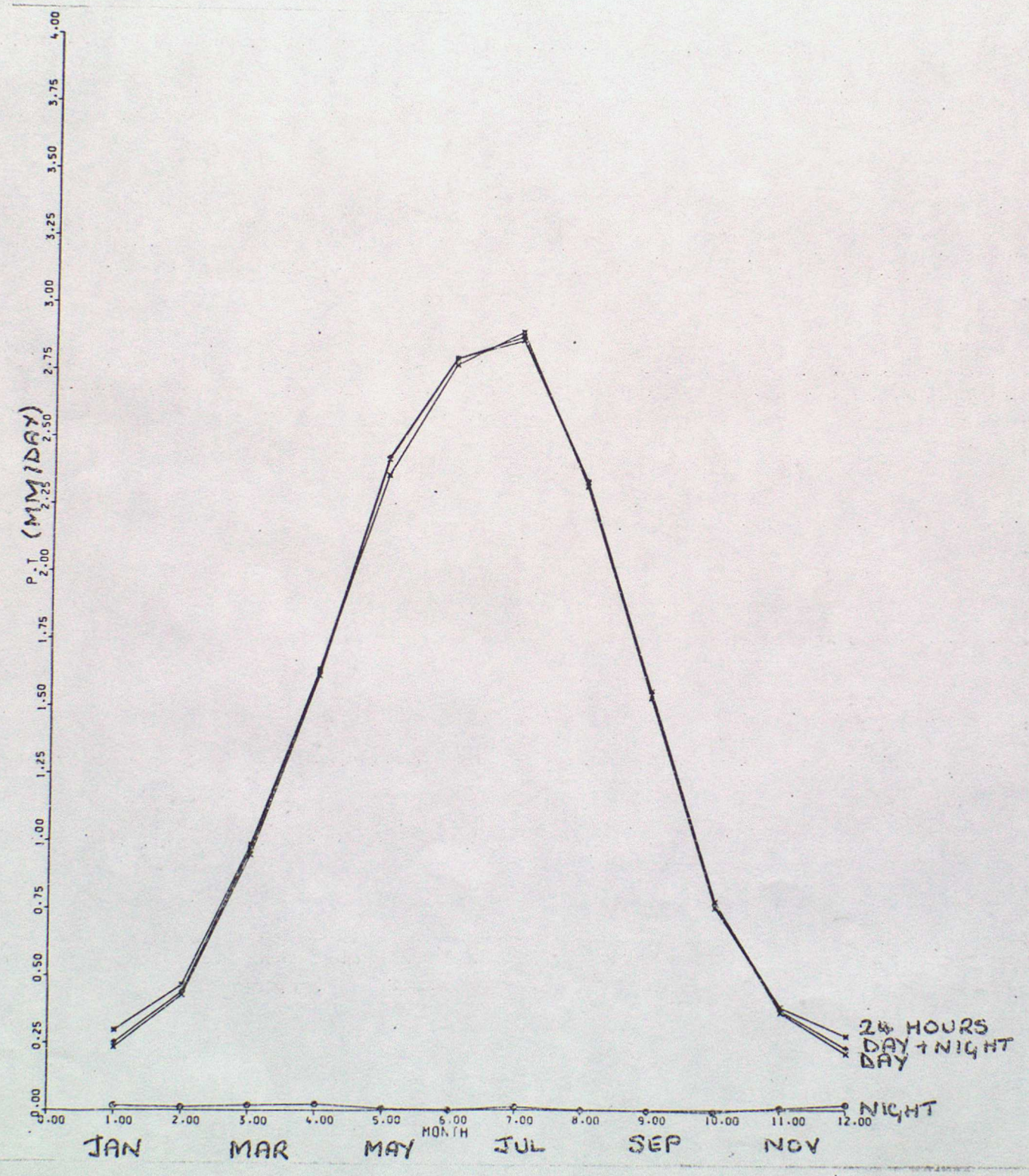


FIGURE 5

Graph to show dependence of m, r_a day and r_a night on z_o

$z_{op} = 1.37$ mm
$z = 1.2$ m $u = 9$ knots

$$m = \left[\frac{\log_e (z/z_{op})}{\log_e (z/z_o)}\right]^2 \qquad r_a \text{ day} = \frac{245}{m\left(1 + .54 \dfrac{\log_e 1.2/z_o}{\log_e 10/z_o}\right)} \qquad r_a \text{ night} = \frac{315 \left(\dfrac{\log 10}{z_o}\right)}{m \times u \times 0.5148 \log \frac{1.2}{z_o}}$$